How do active galactic nuclei affect galaxy cluster and group properties?

Ewald Puchwein, Debora Sijacki *, Volker Springel
MPA Garching, *MPA & IoA Cambridge

Overview

How do active galactic nuclei affect galaxy cluster and group properties?

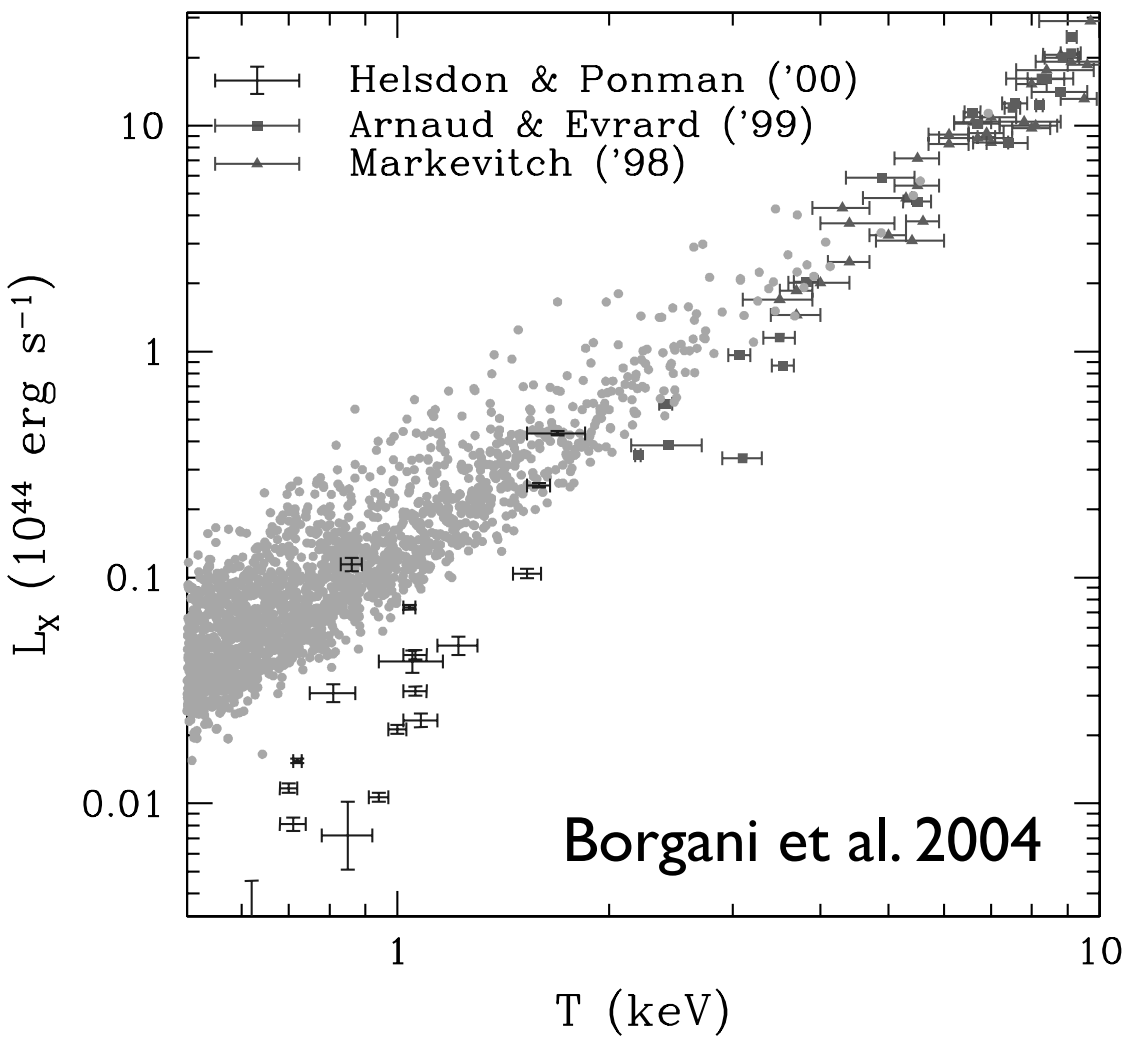
- Motivation for modeling AGNs in hydro-simulations
- Introduction to the model of black hole growth and associated feedback
- Simulations of a group and cluster sample
- Effect on gas and stars in clusters and groups
- Effect on X-ray properties
- Summary

Motivation

Why is it interesting to model black hole growth and associated feedback in simulations?

- cooling flow problem, prevent overcooling
- cluster scaling relations that deviate from the self similar predictions

The L - T relation



The black hole growth model

How is black hole growth modeled in the simulations?

- black holes (BHs) are represented by collisionless sink particles and seeded by a FOF group finder in all halos with

$$M > 5 \times 10^{10} M_{\odot}/h$$

- black hole growth happens by

➡ mergers with other black holes (when their distance and relative velocity is small enough)

➡ gas accretion according to the Bondi-Hoyle-Lyttleton formula

$$\dot{M}_{\rm BH} = \frac{4\pi\alpha G^2 M_{\rm BH}^2 \rho}{\left(c_{\rm s}^2 + v^2\right)^{3/2}},$$

with the Eddington limit imposed

The AGN feedback model

How is the feedback modeled? (also see Sijacki et al. 2007)

- two modes of black hole feedback:
  - ➡ QUASAR MODE, used when the accretion rate is larger than 1% of the Eddington value
  - ➡ RADIO MODE, used when the accretion rate is smaller
- the quasar mode feedback
  - ➡ a small fraction of the luminosity is isotropically, thermally coupled to the surrounding gas particles

$$\dot{E}_{\rm feed} = \epsilon_{\rm f} L_{\rm r} = \epsilon_{\rm f} \epsilon_{\rm r} \dot{M}_{\rm BH} c^2$$

with

$$\epsilon_r = 0.1 \quad \text{and} \quad \epsilon_f = 0.05$$

The AGN feedback model

How does the radio mode feedback work?

- the radio mode feedback

➡ when accretion rate < 1% of the Eddington value
-> recurrent injection of hot (thermal) bubbles

➡ the injection of energy into bubbles is triggered when a BH's mass has increased by a certain fraction $\delta M_{BH}/M_{BH}$

➡ energy thermally injected into bubble:

$$E_{\rm bub} = \epsilon_{\rm m}\epsilon_{\rm r} c^2 \delta M_{\rm BH}$$

with $\epsilon_r = 0.1$ and $\epsilon_m = 0.2$

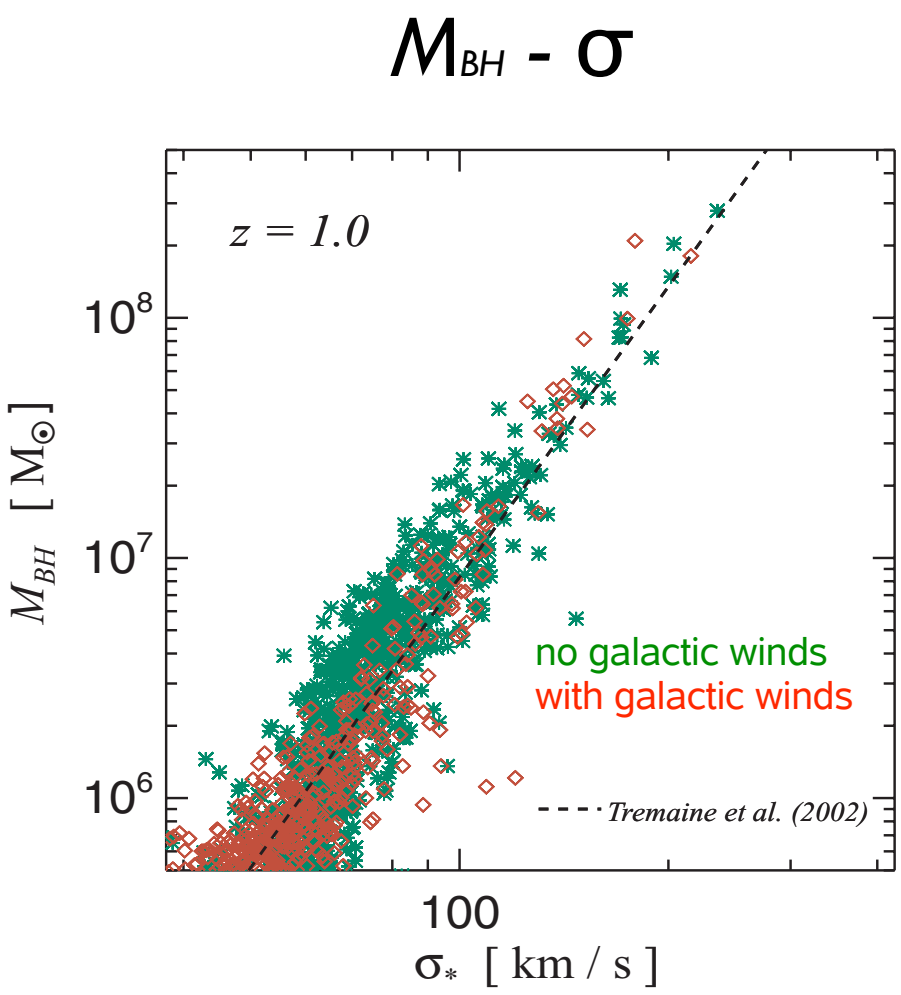
➡ radius of the bubbles:

$$R_{\rm bub} = R_{\rm bub,0}\left(\frac{E_{\rm bub}/E_{\rm bub,0}}{\rho_{\rm ICM}/\rho_{\rm ICM,0}}\right)^{1/5}$$

Previous results obtained with this feedback model

Some of the most important previous results

- this model leads to a self-regulated BH growth
- star formation rates of massive galaxies are reduced and their colors are redder
- M_{BH} - σ is reproduced (not strongly affected by radio mode)



Sijacki et al. 2007

The simulated cluster and group sample

How were the simulations performed?

- zoomed initial conditions for a mass-selected sample of clusters and groups from the Millennium simulation
- performed two kinds of hydro re-simulations of these halos
  - ➡ simulations that employ only the Springel, Hernquist model for cooling, star formation and SN feedback
  - ➡ and simulations that additionally include the model for black hole growth and AGN feedback
- adapted the WMAP 5yr + SN + BAO baryon fraction

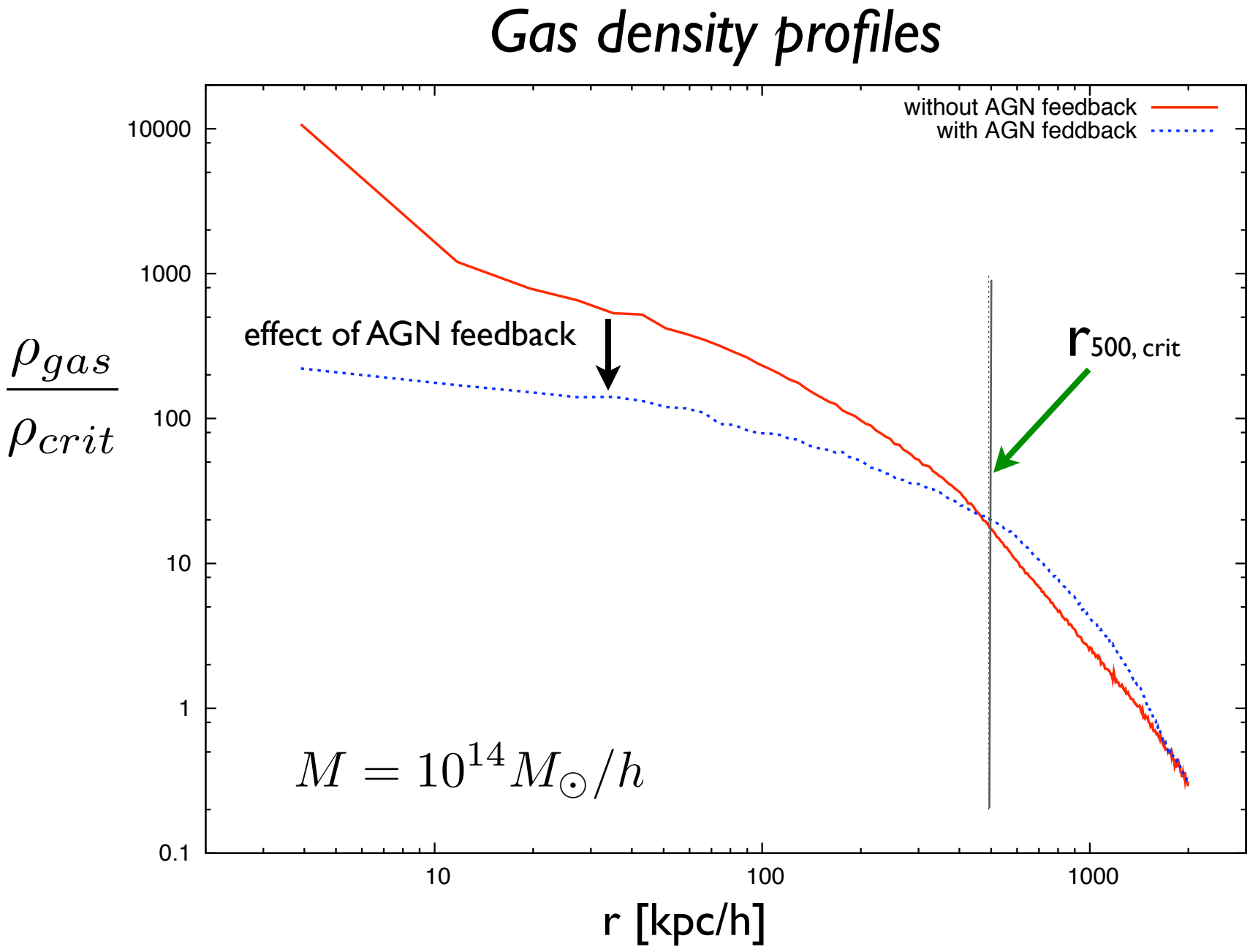
$$\Omega_b/\Omega_m = 0.165$$

- used mass resolution of

$$m_{DM} = 8.8 \times 10^7 M_\odot/h \quad \text{and} \quad m_{gas} = 1.7 \times 10^7 M_\odot/h$$

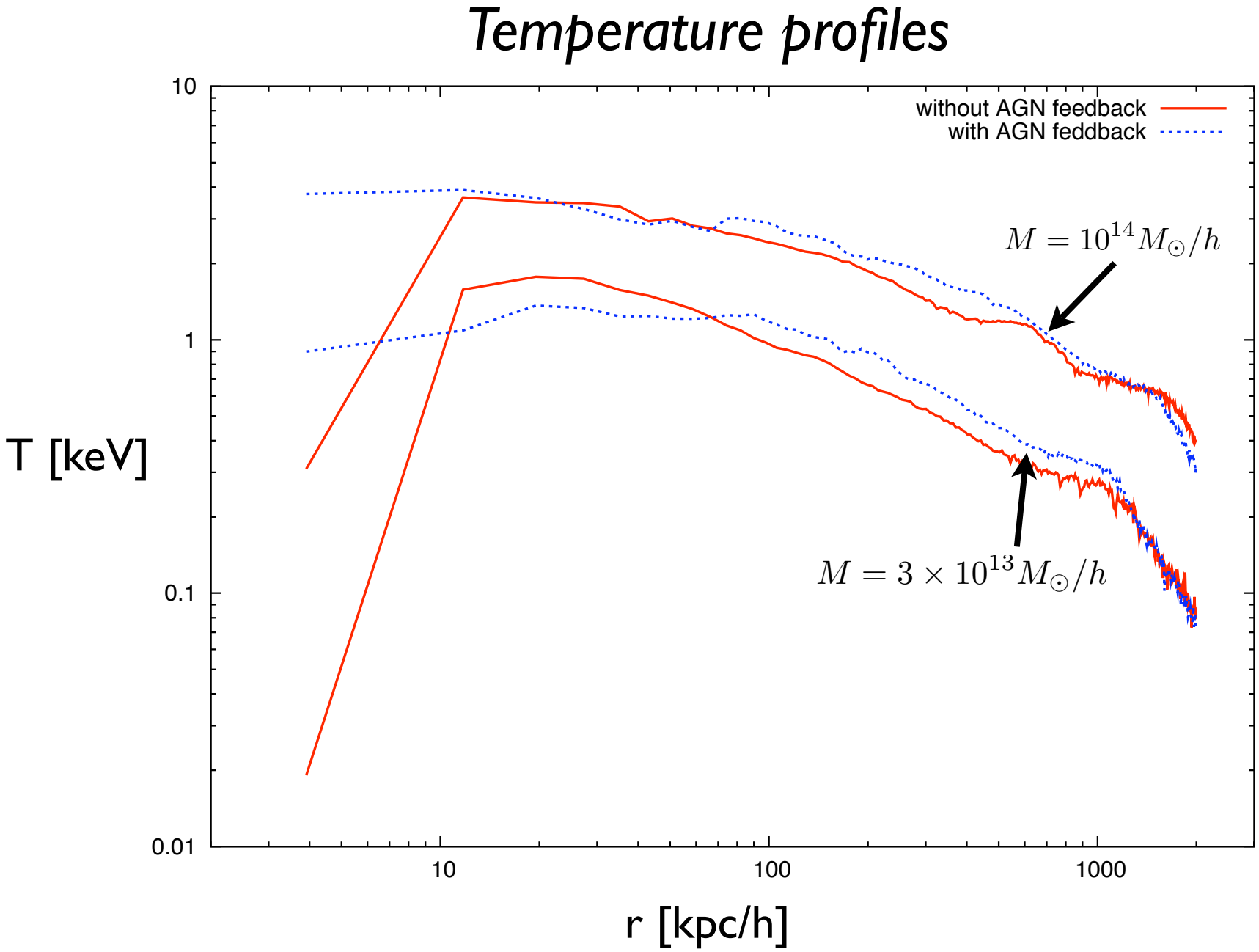
The gas distribution

How is it affected by the AGN feedback model?



The gas distribution

How is it affected by the AGN feedback model?

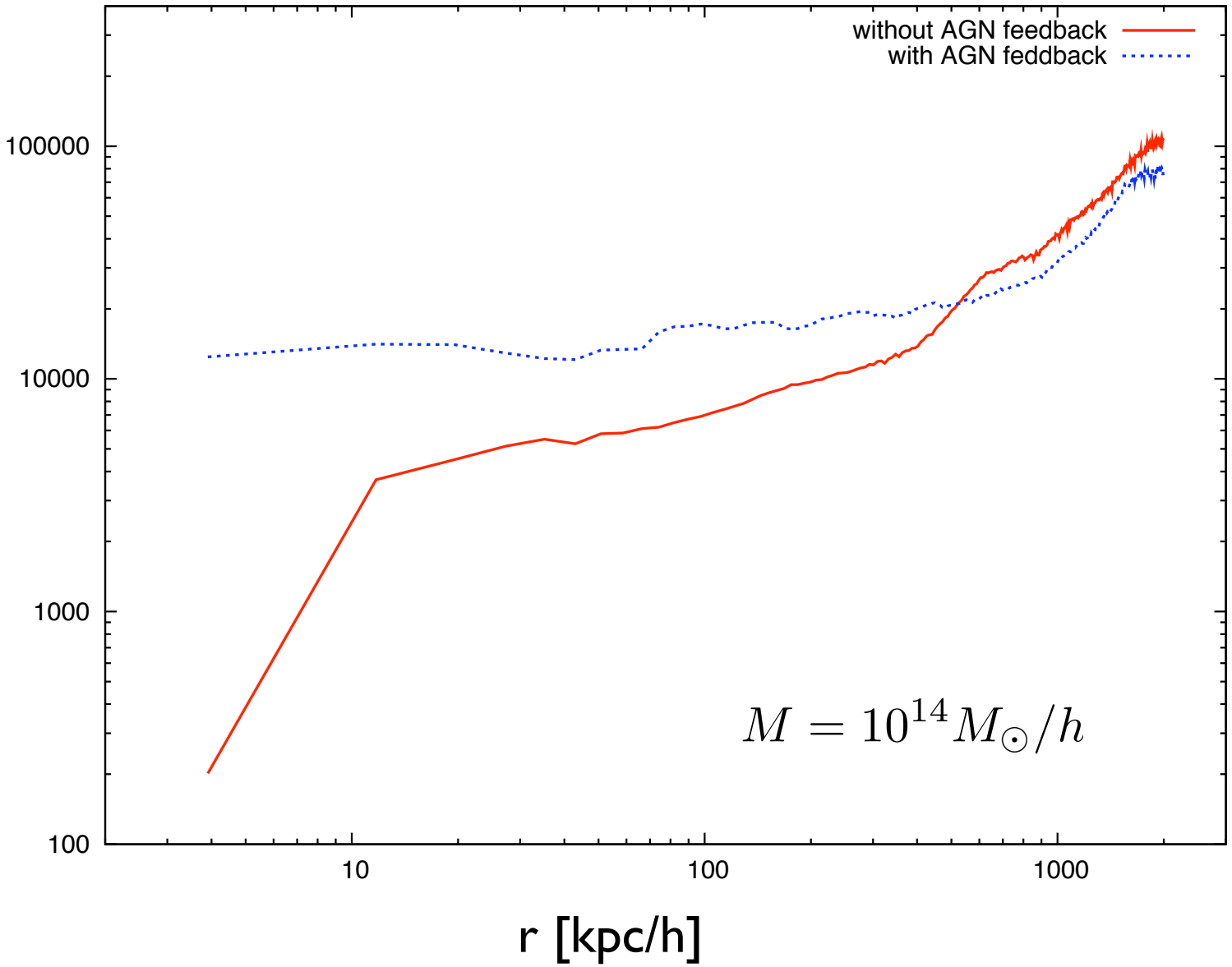


The gas distribution

How is it affected by the AGN feedback model?

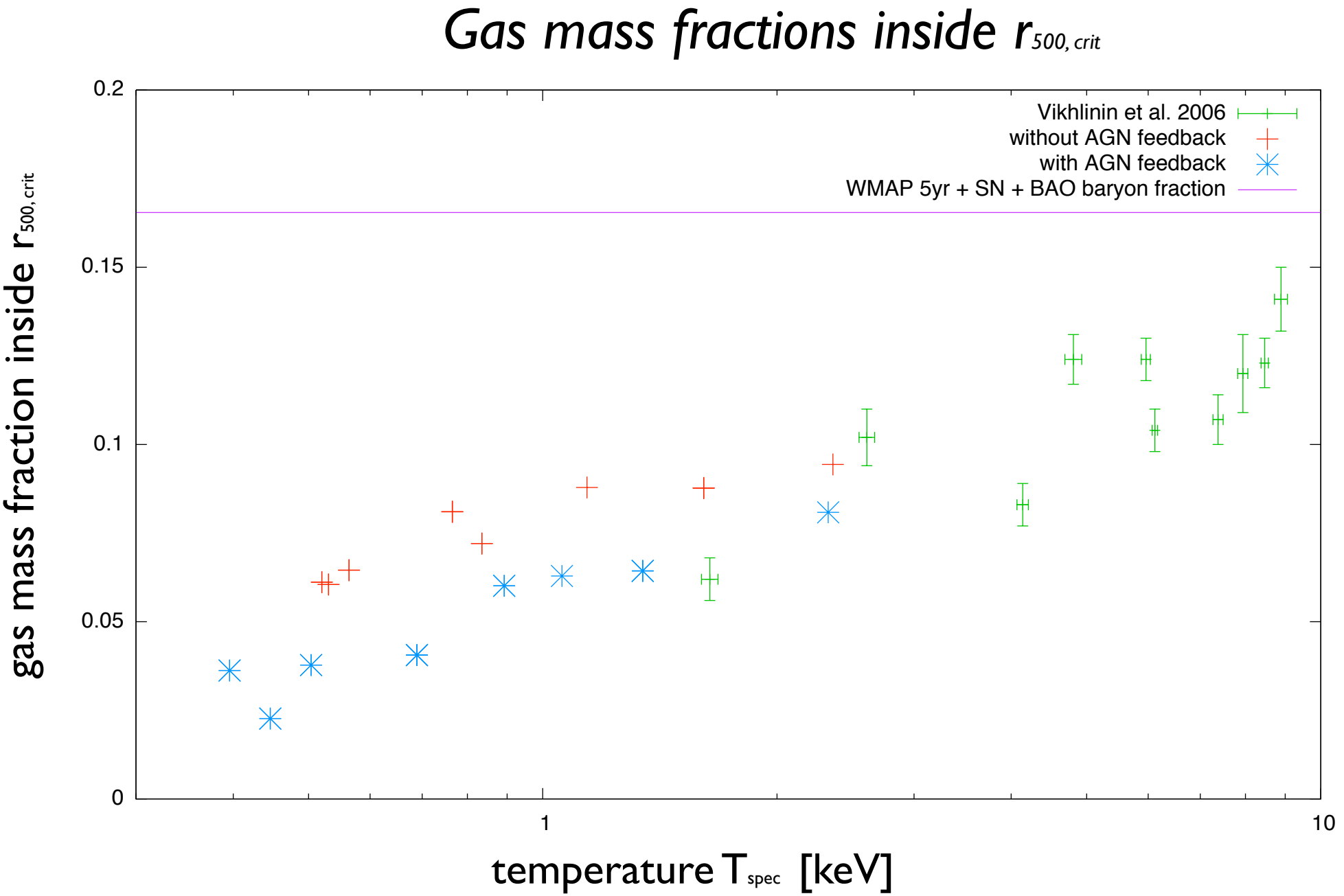
Entropy profiles

$$\text{entropy} \sim \frac{T}{n_e^{2/3}}$$



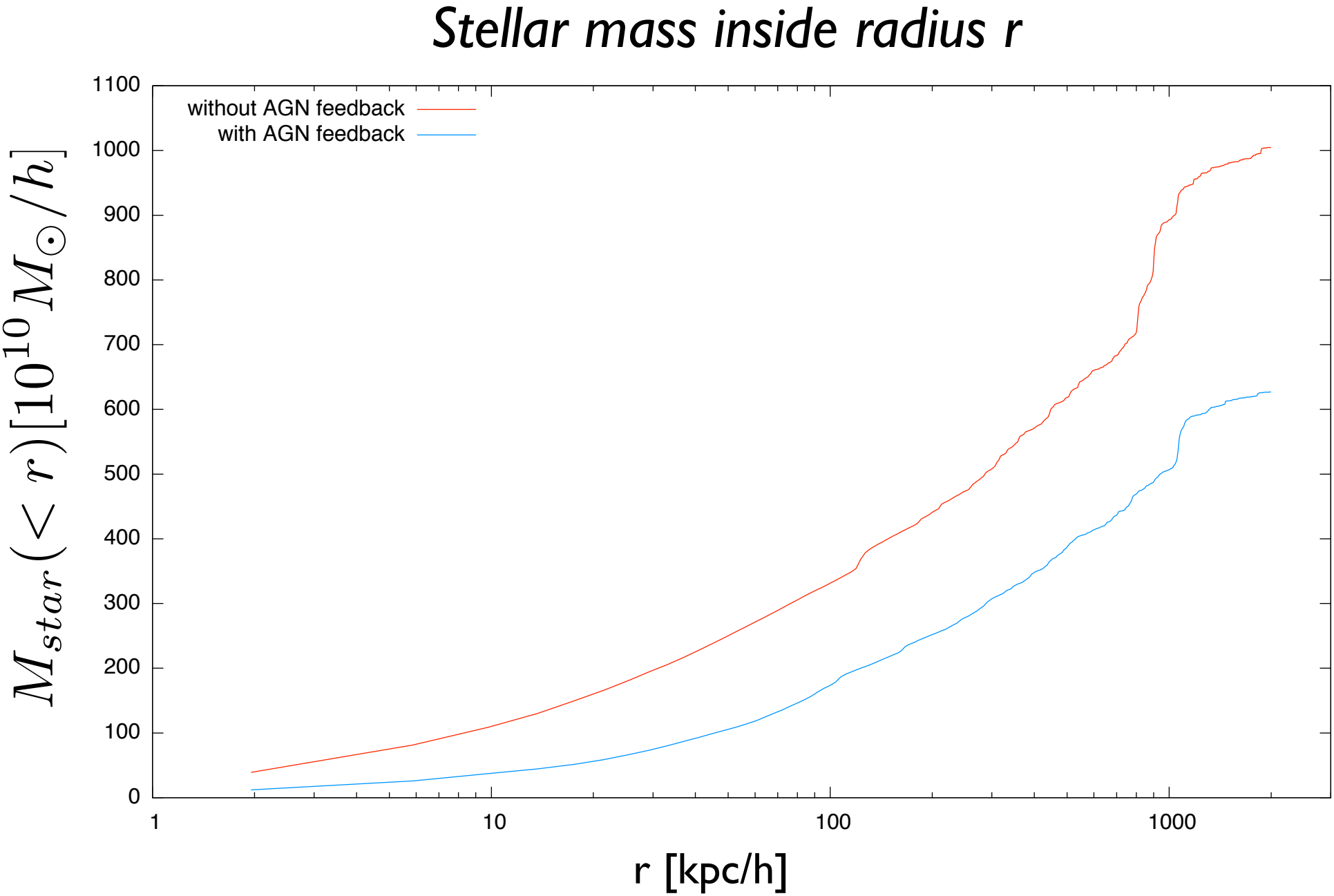
The gas mass fractions

How are they affected by the AGN feedback?



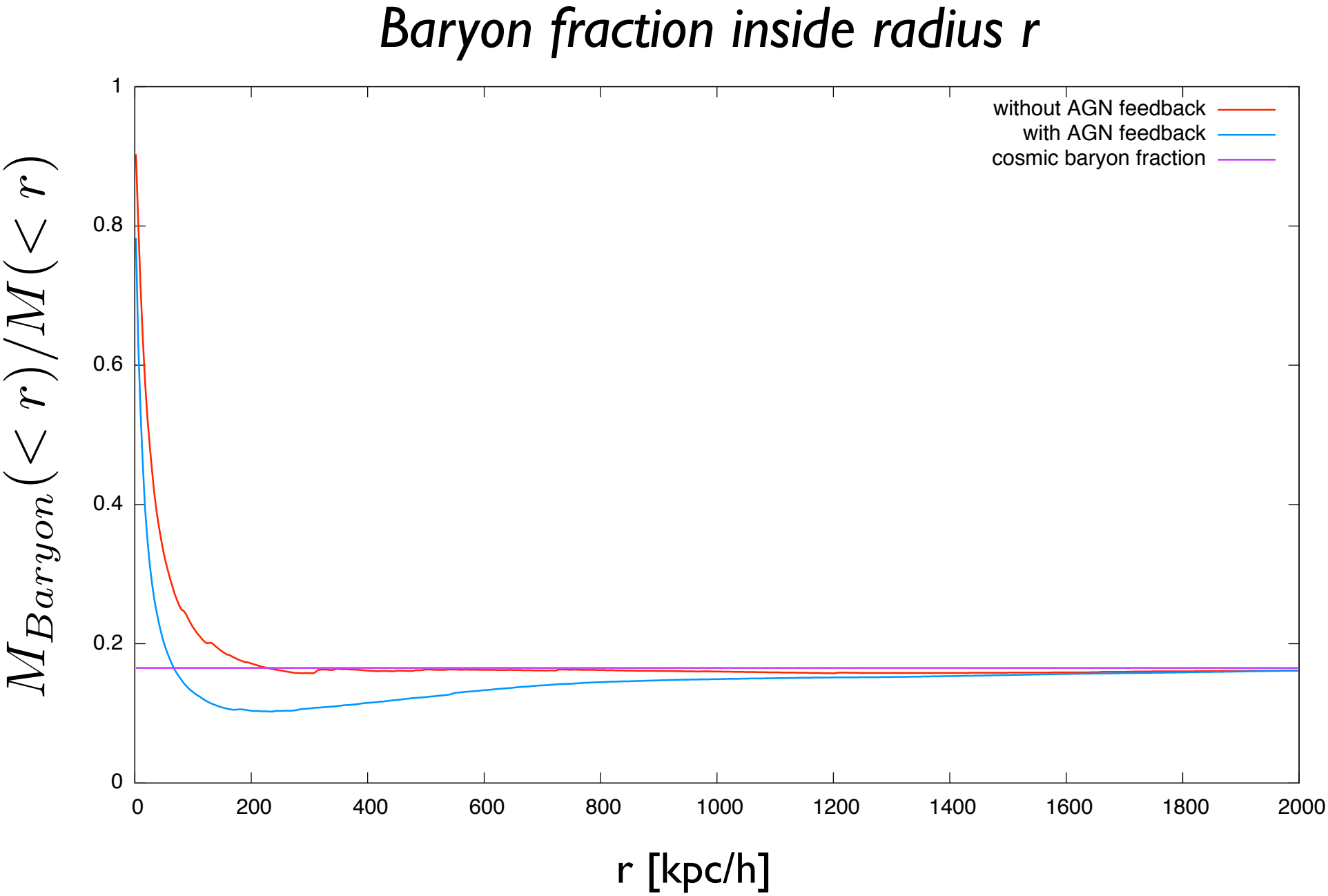
The stellar mass

How many stars are formed?



The halo baryon fractions

How are baryon fractions affected?



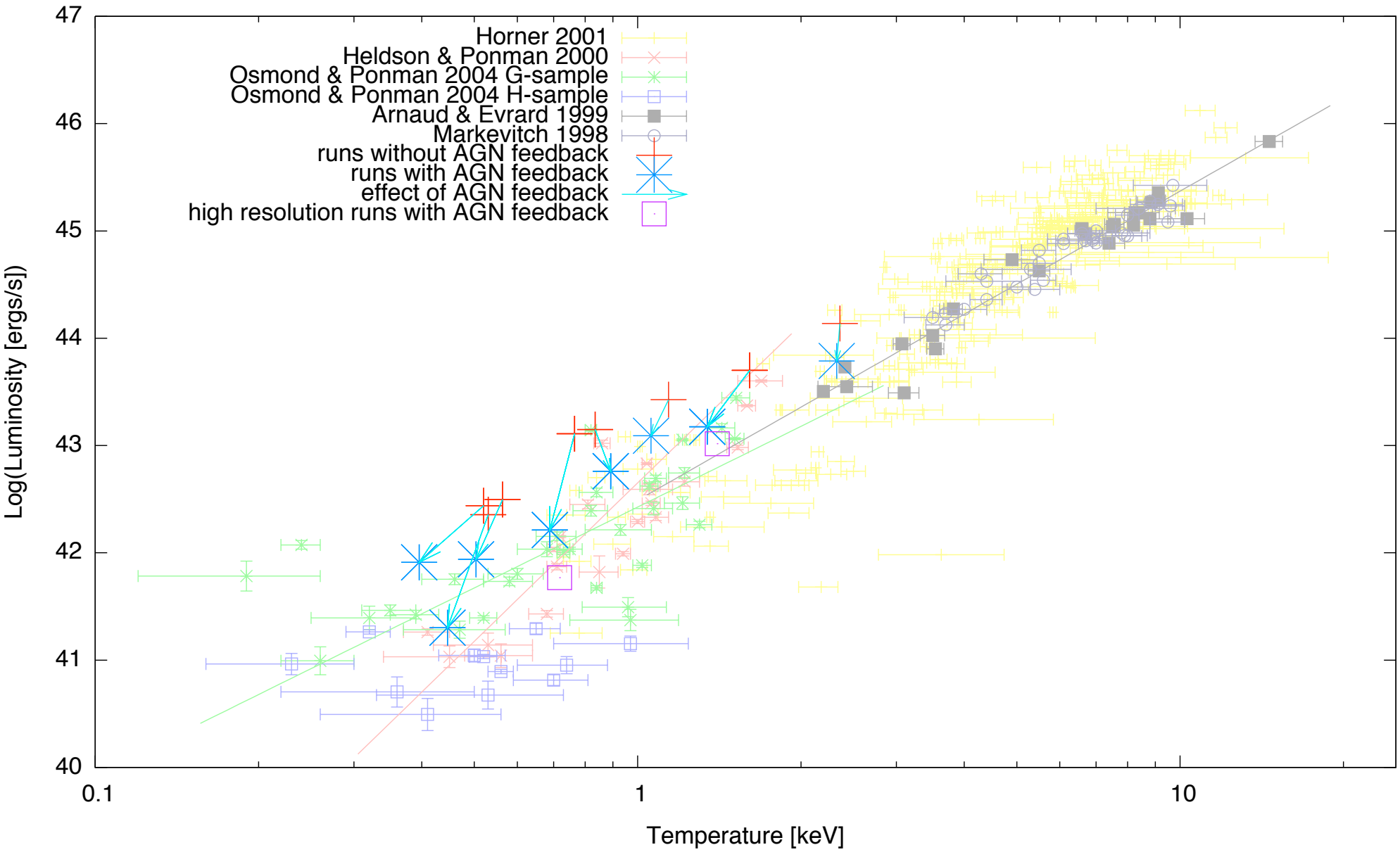
X-ray properties

How were they calculated?

- put all gas particles inside (projected) radius $r_{500,\,crit}$ into temperature bins and sum up the emission measure for each bin
- use XSPEC to simulate a spectrum (using Chandra's response function)
- fit by a single temperature MEKAL model
- obtain spectroscopic temperatures T_{spec} and bolometric luminosities L_{500} from these fits

The L_X-T relation

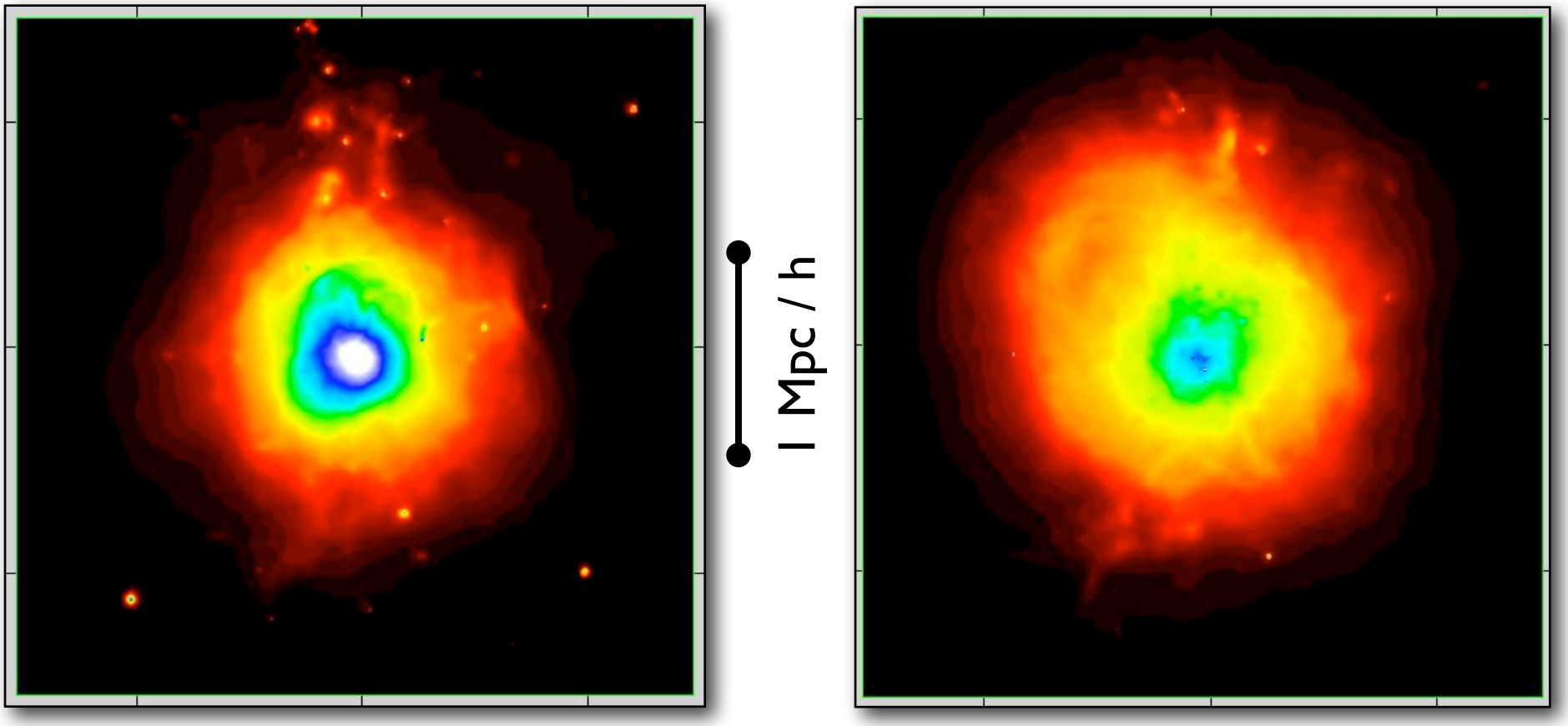
How is it affected by AGN feedback?



Synthetic X-ray observations

What effects can be seen?

X-ray surface brightness



without AGN feedback

with AGN feedback

Summary and Conclusions

The main points of this talk

- performed simulations with a quasar and radio mode AGN feedback model
- significant amounts of baryons are moved away from cluster and group centers
- smaller baryon fractions and more realistic stellar masses
- X-ray luminosities decrease (especially at group scale)
- the simulated L-T relation agrees much better with observations